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Using Computational Models To Create a Word Learning Intervention

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Abstract

The present investigation examines the role of semantic network structure in the mental lexicon of toddlers during language acquisition. The growth principle preferential attachment can be applied to a lexical network; implying networks grow by adding new words based on the connectivity of words already in the network. Aguilar (unpublished) used preferential attachment to create simulations of children's lexical network growth. The following paper is an extension of Aguilar (unpublished) and applies the same preferential attachment algorithm developed for semantic-based features to real children's vocabularies. Using real children's vocabularies offers further insight on what types of words affect a child's mental lexicon and overall vocabulary. In this experimental study, children were given a custom-made picture book containing sixteen words that have either a high- or low-probability of being learned according to the predicted growth of each child's existing vocabulary. Overall, children in both conditions were able to successfully learn the words in their book as measured by a receptive vocabulary pointing task. In addition, findings show a significant difference in whether or not words are acquired differently for different word-learning populations; depending on what words they already know. Findings suggest children benefit from learning words in an intervention when presented with words they otherwise wouldn't learn. The work presented makes two main contributions. The first contribution is a measure of how well children under the age of two respond to individualized storybook interventions. The second is a test of whether the Aguilar (unpublished) models capture some aspect of actual growth.

Intro

The present investigation examines the role of semantic network structure in the mental lexicon of toddlers during language acquisition. Mental lexicon is a term used in psycholinguistics to refer to an individual's internalized knowledge of the properties of words. Previous studies have been done to model adult mental lexicons and their structure (e.g. Steyvers & Tenenbaum, 2005). Findings on how these adult networks grow suggest that the process of semantic growth depends on the connectivity of the existing network (Steyvers & Tenenbaum, 2005). A growth principle that exemplifies how existing structure governs future growth is preferential attachment. Applying preferential attachment to a semantic network would imply that networks grow by adding new words based on the connectivity of words already in the network. Alternative growth principles have been introduced by Hills, Maouene, Maouene, Sheya & Smith (2009) with a focus on order of acquisition in the growing mental lexicon of children. One alternative growth principle examined by Hills *et al* (2009), termed preferential acquisition, is where better connected words in the learning environment (as oppose to more connected words in the child's internal network as in preferential attachment) are learned earlier than less connected words. Another alternative growth principle proposed by Hills *et al* (2009) is called the lure of associates in which new words are added to the lexicon in direct proportion to the number of known words that they are related to. These alternative growth principles indicate that different properties of an emerging semantic network overall may be responsible for contextual diversity and eventual growth as oppose to the properties of an individual word the child currently knows. Despite the emerging interest in these two alternative growth principles, they do have drawbacks due to their recent appearance in the literature. However, Steyvers & Tenenbaum's (2005) claim that the meaning of an individual concept is represented by its pattern of connectivity can also be shown in the lexical structure of word learning in toddlers as supported by Aguilar (unpublished). Aguilar (unpublished) grew lexical networks that emulated the mental lexicon growth of prototypical toddlers using preferential attachment. This growth principle was chosen (over alternative growth principles) because many studies assume phonology and semantics work synonymously (see Hills *et al*, 2009) whereas Aguilar (unpublished) intended to break this assumption. Aguilar (unpublished) focused on 2 distinct feature-types: phonology-based and semantic-based, to better understand the mechanisms driving month-by-month prototypical growth using preferential attachment. Results showed that, compared to a random control, phonology predicts acquired words starting at 22 months, and semantics predicts acquired words starting at 26 months. Overall, the preferential attachment algorithm used in Aguilar (unpublished) does, in fact, model the prototypical growth of toddler's vocabularies better than random indicating such growth may model actual vocabulary acquisition. In spite of this, the method has yet to be applied to real children’s vocabularies. The current study is an extension of Aguilar (unpublished) and uses real children’s vocabularies to better understand what types of words play an integral part in changing a child’s mental lexicon and overall vocabulary. In this experimental study, children were given a custom-made picture book containing words that have either a high- or low-probability of being learned according to predicted growth based on the semantic connectivity of that child’s existing vocabulary. Picture books were chosen because studies have shown that children’s exposure to books is directly related to the development of vocabulary (see Sénéchal & LeFevre, 2002). In sum, this study is the first of its kind in performing an intervention with picture books for children under the age of two, and in testing the applicability of the preferential attachment algorithm from Aguilar (unpublished) to real children’s vocabularies.

Background

The Mental Lexicon

Word learning is a complicated process. It goes beyond a simple one-to-one mapping between word and meaning. As a result, limited space and shared characteristics among brain areas associated with language support the notion of overlapping representations. The mental lexicon itself can be conceptualized as a dictionary containing knowledge of the properties of words. However, the mental lexicon is more than a passive storage repository (Elman, 2004). If a word is broken down, its fundamental components arise: meaning, pronunciation, and syntactic characteristics. The component of interest for this particular study is meaning. However, meaning goes beyond a simple dictionary definition. In fact, the current literature suggests that by 12 months of age, children demonstrate sensorimotor (sensory/perceptual and motor/physical) knowledge about their environment, allowing them to attend to the salient features of the world around them (Bloom, 2002). These sensorimotor features contribute to how children attain information pertaining to new concepts or words. To model this, Howell, Jankowicz & Becker (2005) developed a set of 97 sensorimotor features, each of which illustrated the perceptual and motor nature of a child's language acquisition environment. This feature list includes 19 polar opposite dimensions (i.e. 'size', 'temperature', and 'hardness') and 78 probabilistic features (i.e. 'is red', 'has fur', and 'is delicious'). Findings from Howell *et al* (2005) demonstrate how well the provided sensorimotor features act as a computational representation of the meaning of a word when acquiring language for the first time. Aguilar (unpublished) also used the sensorimotor features developed by Howell *et al* (2005) in creating semantic feature type networks. Overall findings indicate this growth was more similar to actual growth than a random control. In addition, focusing on the features of a word as opposed to the word itself when studying the mental lexicon, merits the use of semantic networks to provide a sense of how certain associations and shared features of two words may play a role in language acquisition. The current study creates semantic networks based on a child's existing vocabulary, using the sensorimotor features developed by Howell *et al* (2005) to determine the connectivity of the network, demonstrating the structure of the child's mental lexicon.

Semantic Networks & Preferential Attachment

Recently, there has been an emerging interest stemming from graph theory in semantic networks. In particular, network scientists are highly interested in focusing on the relationships between entities rather than on the entities themselves when analyzing networks (Mitchell, 2009). This way of thinking has come to be known as “network thinking” (Mitchell, 2009). Using the network thinking approach, Steyvers and Tenenbaum (2005) investigated how well semantic models emulate human semantic knowledge in structure and performance. They constructed graph-theoretic analyses of semantic networks that modeled three semantic knowledge resources: free association norms and two different thesauruses (Steyvers & Tenenbaum, 2005). Findings suggest that despite different origins, the semantic networks all shared distinctive features in their structure. These statistical regularities enticed Steyvers and Tenenbaum to investigate the principles of a growing network model including order of acquisition. A network growth process that exhibited similar statistical regularities is *preferential attachment*. In fact, according to Barabási and Albert (1999), preferential attachment yielded a power-law degree distribution in modeling the World Wide Web, similar to that of the initial networks constructed by Steyvers and Tenenbaum. Power law is the mathematical relationship between two elements whose frequency depends on its size, so the first nodes in a preferential attachment grown network have higher degrees, or number of connections, at the end of growth than their newly added neighbors. The number of edges a node in the network has is its *degree* and the probability distribution of these degrees over the network is the *degree distribution*.

The algorithm driving preferential attachment growth is as follows. Preferential attachment is governed by the idea that some quantified weight is distributed among distinct elements in a set of elements according to their existing weight. Replacing the concept of weight with credit or wealth, the principle that the "rich get richer" is synonymous with preferential attachment; those who are already wealthy tend to receive more wealth than those who are not. Applying this to networks, preferential attachment means that the more connected a node is, the more likely it is to receive new edges. This characteristic could accurately simulate human language learning such that earlier words act as nodes that attract new neighbors (causing them to attain new edges) over time. Steyvers and Tenenbaum (2005) found their simulated networks appropriately matched adult lexical networks created by free association[1], supporting the preferential attachment growth principle in modeling word learning computationally.

Hills *et al* (2009) have introduced two alternative growth principles to preferential attachment that focus on the order of acquisition in the growing mental lexicon of children (see Figure 1). One alternative growth principle examined by Hills *et al* (2009), termed preferential acquisition, is where better connected words in the learning environment (as oppose to more connected words in the child's internal network as in preferential attachment) are learned earlier than less connected words. The second alternative growth principle proposed by Hills *et al* (2009) is called the lure of associates in which new words are added to the lexicon in direct

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[1] Free association is a task where participants are instructed to write down the first word that comes to mind when given a word from a set of word cues one at a time. In the case of the associative network constructed by Steyvers and Tenenbaum (2005), word nodes were connected via an edge if at least two participants reported the same associative response.

proportion to the number of known words that they are related to. Results from Hills *et al* (2009) indicate that different properties of an emerging semantic network overall may be responsible for contextual diversity and eventual growth as oppose to the properties of an individual word the child currently knows.

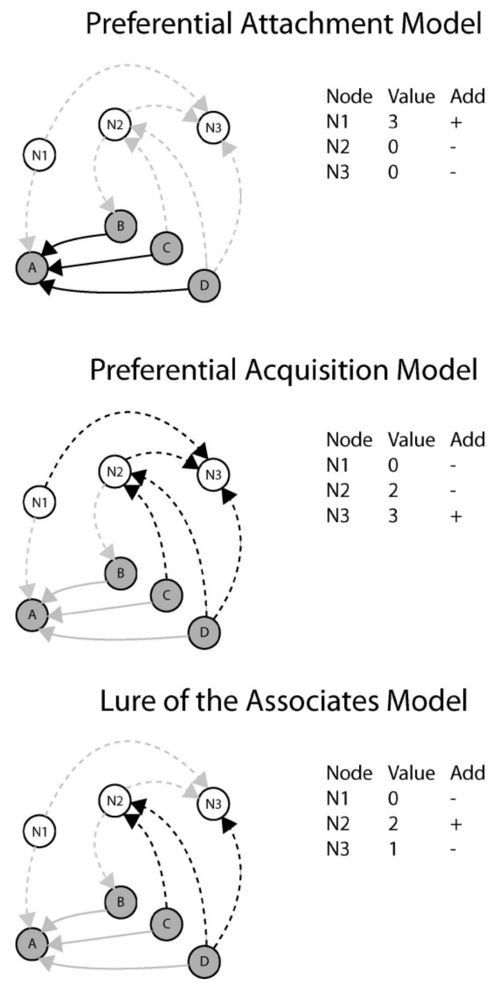

Figure 1: Growth Algorithms (Hills *et al*, 2009)

Despite emerging support that these alternative growth principles may model language acquisition, their actual validity has yet to be proven. Studies done on preferential acquisition and the lure of associates have drawbacks, such as using child directed speech (Hills, Maouene, Riordan & Smith, 2010) or a small subset of the words children learn prior to 30 months (Hills *et al*, 2009) as the basis for growth. Another drawback shown in Hills *et al* (2010) is both preferential acquisition and the lure of associates are outperformed by preferential attachment when looking at descriptive words (adjectives). In addition, both Hills *et al* (2009) and Hills *et al* (2010) assume semantics and phonology work synonymously, which is disputed in Aguilar (unpublished). Thus, these alternative growth principles merit greater evidential support prior to accepting either growth principle as more valid than preferential attachment in modeling toddlers' language acquisition at this time. As a result, the present study explores children's vocabulary, such that a child's language network is made up of acquired words and will yield a predictive growth based on the principle of preferential attachment.

Acquisition of Vocabulary during Storybook Reading

Given the complexity of a child's mental lexicon in and of itself, it is difficult to measure the key variables in a learning environment that encourage vocabulary growth. However, a measurable metric that is used by both speech pathologists for interventions (Kaderavek & Justice, 2002) and parents on a regular basis is the conventional storybook. For many children, storybook reading represents a familiar and meaningful event. Studies have shown that children's exposure to books is directly related to the development of vocabulary (see Sénéchal & LeFevre, 2002). In a five-year longitudinal study, Sénéchal & LeFevre (2002) not only show the importance of book exposure in relation to vocabulary development, but also investigate how subsequent language skills directly relate to children's reading in grade 3.

Additional research shows children construct knowledge through adult-child communicative exchanges during shared storybook-based activities (Kaderavek & Justice, 2002). This is demonstrated though a change in children's verbalizations with repeated exposure to a particular storybook. Repeated exposure allows young children to attend to certain features of the storybook that may have gone unnoticed during prior exposures. In addition, parent-infant interactions with books result in highly regularized interactions, allowing parents to repeat certain verbal behaviors that encourage imitation by the child (Sénéchal & LeFevre, 2001). According to Kaderavek & Justice (2002), through repeated exposure, “children begin to ask fewer questions centered upon the book’s pictures and instead begin asking more questions about the meaning of words” (pg. 397). In fact, the social nature of storybook reading is further supplemented by selecting books that encourage the child to participate either verbally or nonverbally, such as using books with repeated storylines (Kaderavek & Justice, 2002). These interactions encourage children to understand the meanings of important words in a story in order to understand the story itself.

Prior research in relation to storybook reading has been done mostly with Kindergarten-aged children in mind. There are few studies that document how parents read books to very young children (Sénéchal & LeFevre, 2001). For example, Sénéchal & LeFevre (2002) were primarily concerned with the five years contingent upon when children begin to learn basic literacy skills, at four or five years of age. This may be because the book-reading routine tends to change during the transition from preverbal to verbal infancy (Sénéchal & LeFevre, 2001). As a result, how parents read to 9-month-old, 17-month-old, and 27-month old children varies and parents may have different expectations for reading sessions with infants than with older preschoolers (Sénéchal & LeFevre, 2001). The current study attempts to break this norm by focusing on children under the age of two, when vocabulary is just emerging.

It appears a lack of knowledge of words' meanings at a young age stunts vocabulary development and later impacts reading comprehension and later academic success (Christ & Wang, 2010). Earlier interventions may play a key role in preventing stunted vocabulary and later difficulties with literacy skills. Thus, shared storybook reading plays acts as a significant medium for an intervention in promoting emerging literacy skills (see Justice & Pullen, 2003). As a result, these interventions must be carefully constructed. Justice & Pullen (2003) highlight the importance of rigorous design, implementation and evaluation of intervention principles in procedures. Logeman (2000) points out that the use of practices for which evidence is questionable "puts us at risk for slowing children's progress and wasting time precious to their development and learning" (pg. 3). Because we're working in such a sensitive space, the handling of subjects during an intervention is very important. In an attempt to provide general guidelines, research done by Blachowicz, Beyersdorfer & Fisher (2006) points out the basic needs a young child has for developing vocabulary knowledge: (1) exposure to new vocabulary; (2) self-motivation and engagement; (3) multiple exposures to new words that give contextual and definitional information; and (4) the use of independent word-learning strategies. Note that children do not passively acquire words when they simply hear them (Bloom, 2002); they must be actively engaged. The following study has been carefully designed to actively engage children in learning specific words by including a highly prototypical picture with an instance of the new word in each child's custom-made picture book. It has been shown that children's literature in which both illustrations and text provide clues to new word meanings best supports vocabulary learning (Christ & Wang, 2010).

Present Study

The first step of the present study was to conduct a small pilot. As mentioned above, children's progress as word learners is very sensitive (Justice & Pullen, 2003) and the design, implementation and evaluation of this type of intervention should be well-documented and well-understood prior to larger application. This pilot was run with a small sample of children and plays a significant role in narrowing down design decisions. Both the pilot and larger-scale intervention follow a similar methodology: taking the existing vocabulary of a child, growing his/her network through preferential attachment, placing sixteen special words for that child in a custom-made picture book, and performing a receptive vocabulary task for the sixteen words at three different visits: first after being read the book once, second after taking the book home and reading it with a parent about once a day for two weeks, and finally a month after the second visit with no exposure to the book.

There are several goals set for the present study. We wish to extend the work of Aguilar (unpublished) in using the same preferential attachment algorithm and the sensorimotor features developed by Howell *et al* (2005) with real children's vocabularies. By using preferential attachment as the driving growth principle, we can test how well predicted growth measures against actual growth. Pertaining to the use of picture books, we aim to add to the current literature how children under the age of two respond to storybook-based interventions. The use of custom-made books specifically is a measure of how individualized such interventions can be, so subsequently, we are also interested in how customization plays a role in the study. In sum, the overall goals for the present study are to 1) how predicted growth measures against actual growth; and 2) measure how children under the age of two-years of age respond to picture book interventions. The intervention is designed to be age-appropriate and we will measure both vocabulary percentile and receptive understanding of the selected words for each child at each visit to meet the goals outlined above.

Experiment 1

The pilot was conducted in the fall of 2012 and ended in early 2013. The goals of this pilot were twofold: First, this pilot helped us narrow down experimental design decisions including the age of the participants, number of words to include in the book, and methods of testing word learning. Second, this pilot allowed us to settle logistic procedures such as how to secure the initial MCDI (electronically or on paper), when to issue reminders, how many children could be run in what amount of time given all the preparations involved (processing their vocabulary, building their semantic network, running simulations, producing the book), and so on.

Methods

Participants. The study included 8 children: 3 females and 5 males. The participants' ages ranged from 16.4 to 19.7 months (M = 18.4, SD = 1.28). Participants were recruited through a registry of families in and around Boulder County, Colorado. Our registry is publicized to families through a letter from the Colorado State Health Department, information at local daycares, preschools, and magazines. The information in this registry is not published or accessible to the public in any form. Participation when contacted is entirely voluntary. The details of this specific study were explained to parents over the phone or through email prior to coming into the research lab of Dr. Colunga at the University of Colorado at Boulder campus. If the families chose to come in for the study, they were given an informed consent that outlines the research study. This consent ensures that during the task, a parent remains in close proximity to their child at all times during each session. Like all experiments conducted in the research lab of Dr. Colunga at the University of Colorado at Boulder campus, the task is low-risk, age appropriate, and set up like a game. Adhering to these metrics resulted in carefully calculated procedures that allow parents to be assured that the language tasks are similar to those that would be performed at home, reinforcing the notion that participating in the task is low risk for their child.

Procedure Overview. The study had three visits. Prior to the first visit, parents were contacted and asked to complete the MCDI for their child. Once the form was received, the child's vocabulary as reported by their parent was used to create a semantic network. The next step was to run one thousand growth simulations of the order in which the next 50 words in the MCDI were going to be learned. This resulted in an empirically calculated probability distribution for each the words in the MCDI the child did not yet know, representing the probability that each word would be one of the 50 words learned next. From these probabilities, sixteen words were selected depending on the condition the child was assigned to: high-probability or low-probability. The sixteen words selected were put into an individualized book for that child. All this was done in preparation for the child's first visit. At the child's first visit he/she received his/her book and participated in a word learning task. The second and third visits occurred 2 and 6 weeks later respectively and at each of these visits, both the child's vocabulary according to the MCDI and his/her knowledge of the words in their book were measured.

Semantic-Based Features and Word Choice. The 97 sensorimotor features developed by Howell *et al* (2005) were used for semantic-based features. Semantic-based features were chosen over phonology-based features because the current literature indicates children's first categories are likely based on perceptible sensory-motor features (Piaget, 1970). In addition, we could only focus on one feature set, especially for the pilot due to limited time and resources.

In terms of word choice, a subset of 352 nouns has been taken from the Bates-MacArthur Communicative Developmental Inventory (MCDI) toddler version. The full MCDI was administered to parents via email prior to their child coming in for his/her first visit at Dr. Colunga's lab. For the MCDI, parents are instructed to check off the words their child currently says. The MCDI checklist acts as the normative measure for the acquisition of English words toddlers learn and are derived from a normative study of 1,789 children (Dale & Fenson, 1996). Nouns were intentionally isolated from all relational words in this study for a number of reasons. The primary reason is these words can each embody components of the 97 sensorimotor features provided by Howell *et al* (2005). In addition, it is believed that relational words (such as verbs and prepositions) describe a particular perspective on the world according to a speaker as opposed to describing the world directly (Gleitman *et. al*, 1999). Lastly, these words are easily illustrated with a prototypical image alongside the text in the custom-made picture books.

Building networks from sensorimotor features. The distance between two nouns is calculated to examine their relatedness. We start with a semantic-based lexical matrix. This matrix is made such that each row is a word and each of the corresponding sensorimotor values for each word is a column in the same row. Given each row in the provided matrix is the vector representation of a word (in a multi-dimensional space); we calculated the cosine of the angle between the given vector and any other vector in space. Thus, the angle between the noun vector n and any other noun vector, n', the cosine similarity, ɵ can be calculated as illustrated in Equation 1:

$$similarity = \cos(\theta) = \frac{n \cdot n'}{||n|| \, ||n'||} = \frac{\sum_{i=1}^{n} n_i \times n'_i}{\sqrt{\sum_{i=1}^{n} (n_i)^2} \times \sqrt{\sum_{i=1}^{n} (n'_i)^2}}$$

Equation 1: Cosine similarity

with *i...n* as each feature column in the corresponding matrix. In short, the similarity between two words can be calculated such that a higher value indicates greater similarity, maxing out at 1 for a noun's relationship to itself.

These similarity values are then used as a tool to graphically demonstrate the semantic relatedness of a child's vocabulary. A program developed using JUNG (Java Universal

Network/Graph) was used for visualizations and to calculate network measures. Nouns are represented as nodes and an edge is established between two nouns if the similarity value is above the set threshold. A threshold of 0.85 was set, and to reiterate, words at and above 0.85 in similarity have an edge between them. Singletons (words with no connections to other nodes) are not shown. As a result, given a particular lexicon, the connectivity of the network is determined by the edges and can be visibly seen using visualizations. These visualizations provide the opportunity for more detailed analysis on an individual basis for each of the vocabularies provided by parents.

However for the sake of growing the networks, edges were re-represented as a list of pair associates for rapid, efficient growth. In this secondary representation, an edge in the network is a tuple where '(word1, word2)' means word1 shares an edge with word2. The networks are bidirectional; thus, '(word2, word1)' also exists as a tuple in the set of tuples that contains '(word1, word2)'. At this point, the existing vocabulary is being represented and no new words have been added to the network.

The prototypical standard: what networks can grow to be. Prior to growing networks and begin predicting what words children may be ready to learn next based on our computational model, there has to be a standard that each vocabulary has the potential to grow into. The standard vocabulary for children aged 30 months of age is available online from the CDI Advisory Board ("Lexical Norms for English and Spanish Vocabulary", 2003). The MCDI growth trends come from parent reports on 1,803 children to describe the course and variability in language development between 8 and 30 months of age (Fenson et. al, 1994). The restriction set in the given study used to form the prototypical standard was a frequency range from 50% to 100% of the words 30-month-old toddlers are reported to say. In this study, we assumed and were correct that no child in our sample has a more advanced vocabulary than the 30-month-old prototypical toddler. A lexical network was built for the 30-month-old prototypical toddler and the edges set for this vocabulary were used as the standard that vocabularies could grow into.

Simulated Growth. The concept of preferential attachment was used to simulate growth. Original networks were grown 50 words for 1000 runs each. A counter was kept for each new word added and output as how often a word was added out of the 1000 runs, making a summary of the words added in one list. From this list, words were selected and placed in each child's picture book.

Each child was placed in one of two conditions that determined what words would be selected from their summary of words added list. One condition can be considered as high-probability and the top words at the list (closest to 1000) were selected for the high-probability (HP) condition. There were 2 girls and 2 boys in the HP condition (M = 18.35, SD = 1.38). The other condition can be considered as low-probability and words from the bottom of the list (closest to 1) were selected for the low-probability (LP) condition. There was 1 girl and 3 boys in this condition (M = 18.45, SD = 1.39). Sixteen words were selected for each child.

Word Selection. Sixteen words were selected for each child. We wanted to control for the age-of-acquisition for both conditions to ensure that each child had an equal chance of learning the words despite the condition he or she was in. The standard vocabulary for children aged 16-30 months of age is available online from the CDI Advisory Board (“Lexical Norms for English and Spanish Vocabulary”, 2003). With this information, we derived age-of-acquisition for each of the 352 nouns by looking at what age 50% to 100% of children were reported to say the noun. This value was calculated for each of the 352 nouns and averaged across the 16 selected words for each child. Thus, words selected for each child in each condition were based not only on his/her probability list, but also on average age-of-acquisition across all sixteen selected words.

Creating the Custom-Made Picture Books. The sixteen words chosen for a given child is placed in a book titled Where Can Piggy Take A Nap? The premise of the book is a sleepy pig is questioning where to take a nap. Each of the sixteen words are placed with a prototypical picture of the noun, *n* and is placed on the opposite page of the pig with the words "On a *n*?" where "a" is changed to "some" accordingly. So if one of the sixteen words happened to be present, the book would read something like "Where can piggy take a nap?" with a picture of the pig placed above the text then "On a present?" with a picture of a present above the text on the opposite page (see Appendix A). The book ends with piggy deciding to take a nap on a "piggy bed". I read the book once to each child at his/her first visit then asked parents to read the book about once a day until their second visit (10-15 days later) and record when they read the book in the back flap of the book. At the second visit, the books were temporarily taken from the family and returned at the end of the third visit.

Receptive Vocabulary Pointing Task. For the first visit, children were tested immediately after reading the book to assess learning. The task set up measured receptive vocabulary or children's comprehension. This task involved a warm-up where children were shown three illustrated cards, one of which was a ball, and asked to point to the ball. Children were given assistance through the training stage to help them understand what was being asked of them. After the warm-up, the testing stage consisted of showing children 3 illustrated cards, one of which was a target word that had appeared in their custom-made picture book and asking them to point to that target word. This was done for each of the 16 target words.

At the second visit, right when families came in they were asked to update the previously emailed MCDI with any new words their child currently says. Then the same receptive vocabulary task was done. The third visit was identical to the second visit.

Results

Results from this experiment can be laid out quantitatively (see Table 1). Here, children are coded with condition and gender such that “LP” and “HP” represent low-probability and high-probability while “M” and “F” represent male and female, respectively.

For the measure of MCDI, the checklist was administered via email prior to children coming into the lab, at visit 2, and at visit 3. Just from looking at the pre-visit 1 MCDI percentiles, we see that the vocabularies of children in this sample are quite varied, a confounding variable that may affect their word learning overall. Between pre-visit 1 and visit 2, the majority of MCDI percentiles went up with the exception of LP-F1 and HP-M2. This is probably due to a change in month categorization such that a child 19.9 months is considered a 19 month old for calculating his or her MCDI percentile, but considered a 20 month old once they turn 20 months of age. Between visit 2 and visit 3, MCDI percentiles went up again with the exception of LP-M1. LP-M1 most likely encountered the same month categorization change mentioned above.

For word learning, if the child correctly identified the target word in the receptive vocabulary pointing task, he or she was given one point out of sixteen. Word learning proportion was calculated as how many points a child scored out of the sixteen possible points. No data was collected for visit 1 for LP-M2 due to experimental error and for LP-F1 because the book was sent via mail instead of rescheduling a visit 1. All children did better on the second visit than the first visit in the receptive vocabulary pointing task. For visit 3, most children did better than in visit 2. LP-M1 did the same and HP-M2 did a little worse.

		MCDI			Word Learning			Word Learning Proportion		
Participant	Age	Pre-Visit 1	Visit 2	Visit 3	Visit 1	Visit 2	Visit 3	Visit 1	Visit 2	Visit 3
LP-M1	18.6	98.51	99	97.98	5	10	10	0.313	0.625	0.625
LP-M2	19	1	10.71	17.72	ND	3	6	ND	0.188	0.375
LP-M3	16.5	13.33	44.17	53.64	4	9	13	0.267	0.6	0.867
LP-F1	19.7	13.13	7.78	18.33	ND	15	15	ND	0.938	0.938
HP-F1	19.7	85.76	93.47	94.49	6	8	16	0.375	0.5	1
HP-F2	18.6	34.55	45.59	59.44	3	7	12	0.188	0.438	0.75
HP-M1	18.7	58.89	67	88.06	2	5	7	0.125	0.313	0.438
HP-M2	16.4	11.67	10	17.5	5	12	10	0.333	0.8	0.667

Table 1: Results from Experiment 1

An additional measure that can be look at quantitatively is when each child learned one of the sixteen selected words placed in his or her book (see Table 2). This can be measured by looking at whether the selected words were checked off by parents filling out the MCDI. Looking at LP-M1 and HP-F1, we see that words were known prior to the child receiving the custom-made picture book, pre-visit 1. This indicates a faulty version of the preferential attachment program was used. Excluding those two, it appears most children learn less than half of the words by visit 2 (or none in the case of HP-M2). More of the selected words are learned between visit 2 and visit 3, but this is still less than half for the majority of the children. HP-F2 and HP-M1 learned the selected words most and were the only two that learned more than half of the selected words at the end of the experiment aside from the two with faulty programs.

		Selected Words Learned (out of 16 target words)		
Participant	Age	Pre-Visit 1	Visit 2	Visit 3
LP-M1	18.6	13	15	16
LP-M2	19	0	2	4
LP-M3	16.5	0	2	3
LP-F1	19.7	0	0	4
HP-F1	19.7	8	12	15
HP-F2	18.6	0	5	9
HP-M1	18.7	0	6	12
HP-M2	16.4	0	0	1

Table 2: Selected Words Learned Results from Experiment 1

The findings from this experiment are mostly qualitative. The experiment was conducted in a pilot fashion, to be better informed for a larger-scale experiment. The most prevalent finding was that participants in this study were too young. It was difficult to pass training for many of the children despite knowing what a “ball” is and which card was the ball. As for the testing, sixteen rounds were too many and children often got fussy.

The warm-up task may not have been clear to children. Even though most could identify a “ball”, doing so amongst 3 cards was difficult for some.

In addition, a lot seemed to be going on between pre-visit 1 and visit 2 in terms of vocabulary. We didn't have an in-between benchmark of what vocabulary looked like at visit 1 because we assumed it would be about the same as when parents emailed their child's MCDI to us. To reiterate, it is unclear whether children had learned the selected words just before visit 1, but after their pre-visit 1 MCDI had been sent to us because we didn't administer the MCDI at visit 1. Note that the MCDI was administered at visit 2 and visit 3 prior to the receptive vocabulary pointing task.

Logistic findings are as follows. When it comes to administering the MCDI, all parents successfully emailed the electronic version of the MCDI, but doing so was much more difficult than filling out the hard-copy in person at the beginning of visit 2 and visit 3. However, this meant we had to make an electronic copy for our purposes from each hard copy. Reminders were issued one day before appointments to ensure parents didn’t forget to come in for appointments. This fared well, but if appointments weren’t scheduled at the end of the first or second visit for the following visit, scheduling tended to be a little more complicated. Being a full-time student, I could only run a couple kids a day in lab for each of their visits. What really took a tremendous amount of time was processing children’s networks and making their custom-made picture books. I found it was best to allow two whole weeks before families came in for their first visit after receiving their electronic MCDI for their child. Any shorter amount of time may have caused the errors in the program or word selection seen here in experiment 1.

Discussion

Results indicate some changes needed to be made to our procedure prior to performing experiment 2. We decided to move the age group up from 18 months plus or minus 45 days to 20 months plus or minus 45 days. We figured this age group would still capture whether our intervention was effective with children under the age of two, but would allow children to be just old enough to better understand and sit through the receptive vocabulary pointing task.

More careful word selection was merited. The preferential attachment algorithm was debugged and we ensured the same code was used for all children. Selected words were also double checked against the child's pre-visit 1 MCDI to ensure the child did not know the words in his or her book to the best of our knowledge.

The receptive vocabulary pointing task warm up was modified. Now children would be shown two cards, one with a ball and one with a distractor and asked for the ball. If children passed this warm-up twice, they would move on to the second warm-up. For the second warm-up, children are shown three cards, one of which is a spoon and asked for the spoon. Once children can do the 3 cards warm up twice, the testing phase begins. The testing phase is the same with one target and two distractors where the child is asked to point out the target card.

To create a more informed dataset, we decided to administer the MCDI at the first visit prior to the receptive vocabulary pointing task. In addition, all logistical findings were taken into careful consideration to create a more streamlined procedure for each child.

Experiment 2

Experiment 2 was conducted in early 2013 and is expected to finish in mid-May 2013. Like Experiment 1, it consists of three visits, two of which have concluded to date for 22 participants.

Methods

Participants. There were 25 participants, 14 girls and 11 boys (M = 21.28, SD = 1.30). Recruiting was conducted in the same way as in Experiment 1.

Building Networks, Simulated Growth and Constructing the Custom-Made Picture Books. The networks were constructed the same way as in Experiment 1 and simulated growth was performed again using preferential attachment with 50 words for 1000 runs. Conditions were the same two conditions for Experiment 1: high-probability and low-probability. There were 13 children in the high-probability condition, 7 girls and 6 boys (M = 21.28, SD = 1.35). There were 12 children in the low-probability condition, 7 girls, 5 boys (M = 21.28, SD = 1.31).

Selected words were carefully chosen and double checked to ensure the child didn't say the words prior to their first visit according to the electronic MCDI parents had emailed. The age of acquisition was averaged for each condition. For high-probability, M = 23.75, SD = 0.16 and for low-probability, M = 23.79, SD = 0.24. This further ensured that the words selected were matched by age of acquisition for both conditions.

Receptive Vocabulary Pointing Task. For the first visit, parents were first asked to fill out a hard copy of the MCDI, updating new words their child could say since emailing an electronic copy of the MCDI to us. Then, children were read their custom-made picture book once. Children were tested immediately after reading the book to assess learning similarly to what was done in experiment 1. The task set up measured receptive vocabulary or children's comprehension. This task involved two warm-ups. For the first warm-up, children were shown two illustrated cards, one of which was a ball, and asked to point to the ball. After successfully pointing to the ball for two trials, children did a second warm-up. For the second warm-up, children were shown three illustrated cards, one of which was a spoon, and asked to point to the spoon. After successfully pointing to the spoon for two trials, testing began. Children were given assistance through the training stage to help them understand what was being asked of them. After the warm-up, the testing stage consisted of showing children 3 illustrated cards, one of which was a target word that had appeared in their custom-made picture book and asking them to point to that target word. This was done for each of the 16 target words.

At the second visit, right when families came in they were asked to update the previously emailed MCDI with any new words their child currently says. Then the same receptive vocabulary task was done. The third visit will be identical to the second visit.

Results

Results reported are for the 22 children whom have completed second visits. The remaining children are scheduled for second visits, but unfortunately their data is not reported here. The 22 children include 12 children in the high-probability condition, 6 boys and 6 girls and 10 children in the low-probability condition, 4 boys and 6 girls. Overall, children in both conditions were able to successfully learn the words in their book as measured by a receptive vocabulary pointing task. After two weeks with their book, children could identify on average 14 out of 16 words in the high-probability condition, and 13.4 out of 16 words in the low-probability condition. We predicted that children in different conditions would learn words differently based on condition. This is a measure of how well the models represent real language acquisition. Thus, words learned were quantified by the receptive vocabulary pointing task. Children's words learned from their custom-made books immediately after receiving their book (at visit 1) and after having read the book once a day for two weeks (at visit 2) were submitted to a 2 (word type: high-probability, low-probability) x 2 (visit: visit 1, visit 2) repeated measures ANOVA. We found there was a main effect of visit, $F(1,20) = 19.069$, $p < 0.001$). Children know more words from the book at their second visit than their first visit. There were no other significant effects or interactions (see Figure 2).

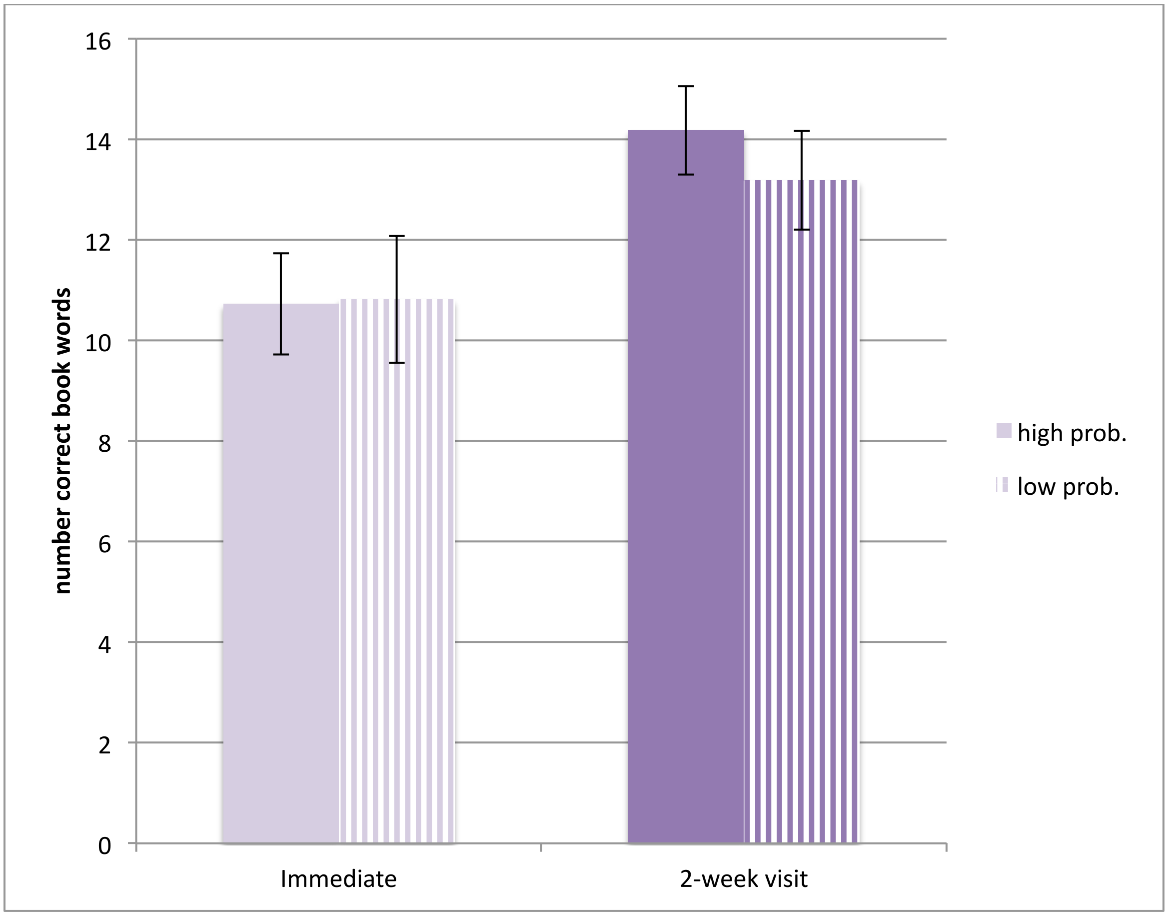

Figure 2: Words learned at visit 1 (immediate) and visit 2 (2-week visit) for all children.

The second goal of this experiment was to see whether a model-based individualized intervention could improve a child's vocabulary in general. This cannot be measured by just an increase in absolute number of words learned, but an increase in the number of words children learned relative from what one might have expected them to learn according to their MCDI percentile. Thus, the results reported here are on the children's vocabulary growth as measured by their *change in MCDI percentile* before they received their book (visit1 – pre-visit) and after they spent two with their book (visit2 – visit1). We predicted that children in the high-probability and low-probability word type conditions would show different percentile change. The children's percentile changes before and after the intervention were submitted to a 2 (word type: high-probability, low-probability) x 2 (percentile change: before, after) repeated measures ANOVA. We found there was a main effect of visit, F(1,20) = 8.56, p = 0.008. Children increase their percentile more from visit 1 to visit 2 (after the intervention) than from pre-visit 1 to visit 2 (before the intervention). There were no other significant main effects of interactions (see Figure 3).

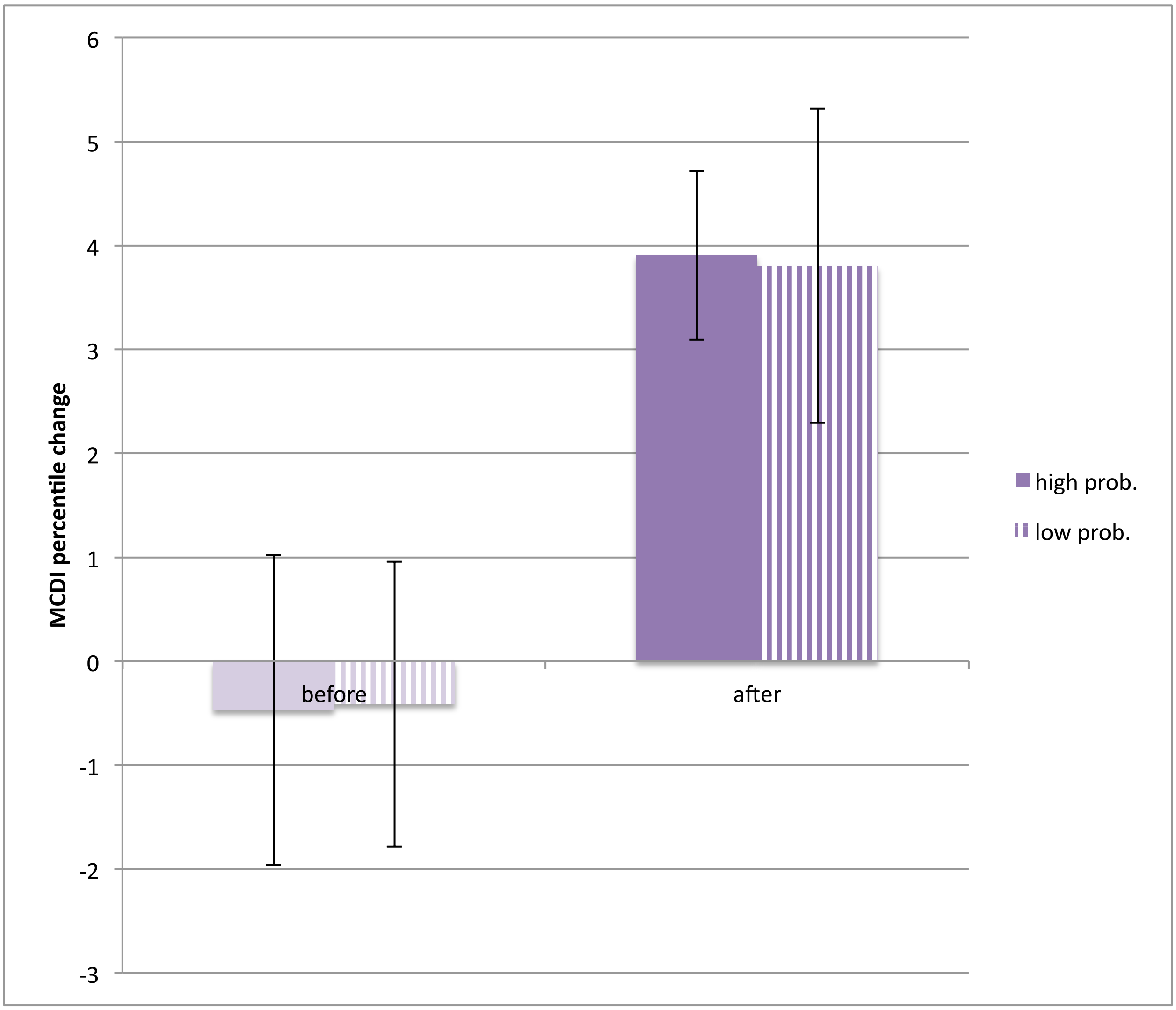

Figure 3: MCDI percentile change before and after intervention for all children

However, children who acquire language differently may be affected by this intervention in different ways. Late-talkers are children who have a delay in expressive vocabulary in comparison to what is typical for their age, but have no neural or sensory deficits and otherwise display typical development in every way (Demarais, Sylvestre, Meyer, Bairati, Rouleau, 2008). Aguilar (unpublished) tested the models using MCDI norms, in a “prototypical” child. Perhaps the models are good at capturing word learning that does not deviate much from this average, but not so good at capturing word learning in late talkers. As a result of different language learning, late-talkers may exhibit differences in vocabulary composition. Late-talkers can be identified in our sample as children whose pre-visit 1 vocabulary is at or below the 25th percentile. There were 3 late-talkers in the high-probability condition ($M = 21.933$, $SD = 1.14$) and 4 late-talkers in the low-probability condition ($M = 20.55$, $SD = 1.39$). Typically developing children then are those between the 25th and 75th percentile. There were 8 typically developing children in the high-probability condition ($M = 21.325$, $SD = 1.44$) and 7 in the low-probability condition ($M = 21.4$, $SD = 1.07$). We added child type as an independent variable to run further analyses.

Taking child type into consideration, we ran a 2 (word type: high-probability, low-probability) x 2 (child type: late talker, typically developing) x 2 (visit: visit 1, visit 2) mixed ANOVA on words learned indicated by the receptive vocabulary pointing task. There was a main effect of visit, $F(1,18) = 18.02$, $p < 0.001$. There was a main effect of child type, $F(1,18) = 8.47$, $p = 0.009$. There was also a 3-way child type x word type x visit interaction, $F(1,18) = 4.66$, $p = 0.045$. We ran a 2 (word type: high-probability, low-probability) x 2 (visit: visit 1, visit 2) mixed ANOVA for late-talkers and found no significant main effects or interactions. However, when we ran a 2 (word type: high-probability, low-probability) x 2 (visit: visit 1, visit 2) mixed ANOVA for typically developing children, things got interesting. We found a main effect of visit,

$F(1,13) = 26.03$, $p < 0.01$. We also found a 2-way interaction for word type and visit, $F(1,13) = 8.34$, $p = 0.013$. Typically developing children know more words at visit 2 in the high-probability condition than in the low-probability condition. A two-tailed t-tests also showed the difference at the second visit in plain number of words, $t(13) = 2.24$, $p = 0.04$ (see Figure 4).

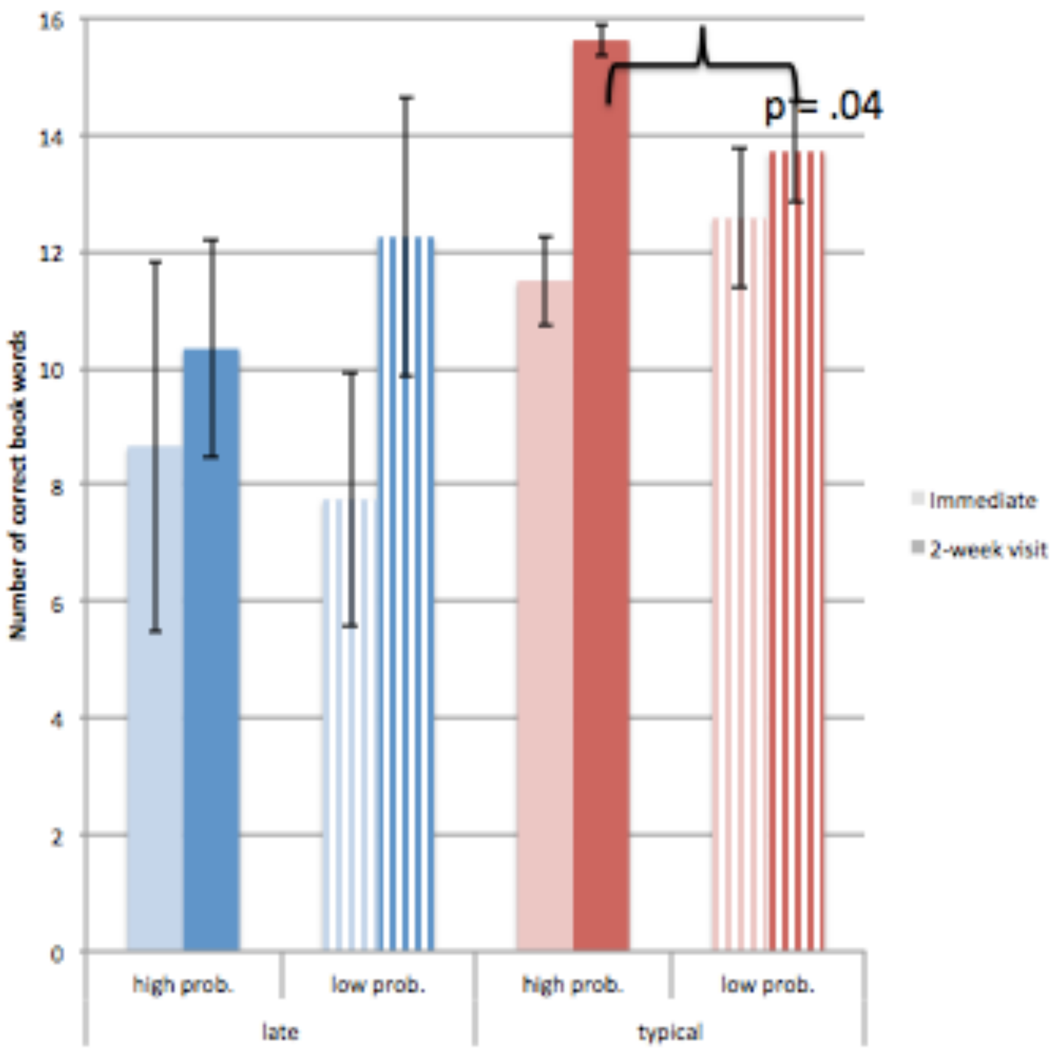

Figure 4: Words learned at visit 1 (immediate) and visit 2 (2-week visit) for late-talkers and typically developing children.

A 2 (word type: high-probability, low-probability) x 2 (child type: late talker, typically developing) x 2 (percentile change: before, after) mixed ANOVA yielded a main effect of visit, $F(1,18) = 7.34$, $p = 0.014$. In addition, there was a marginal main effect of child type, $F(1,18) = 3.49$, $p = 0.78$, suggesting that typically-developing children increased in percentile more than late talkers overall (average percentile change for late talkers: $M = 0.16$, $SE = 0.99$; for typically developing children: $M = 2.25$, $SE = 0.94$). There was also a marginal 3-way interaction of word type by child type by percentile change, $F(1,18) = 3.46$, $p = 0.079$. No other interactions were significant. To further explore the three-way interaction, we conducted two separate 2-way ANOVAS, one for percentile change before the book, and another for percentile change after the book. As expected, there were no significant effects of child type or word type before the intervention. A 2 (word-type: high-probability, low-probability) x 2 (child type: late talker, typically developing) ANOVA yielded no significant effects or interactions. However, the 2 (word-type: high-probability, low-probability) x 2 (child type: late talker, typically developing) ANOVA on percentile change after the intervention (visit 1 to visit 2) yielded a main effect of child type, $F(1,18) = 6.51$, $p = 0.02$, indicating that typically developing children benefitted from the intervention more than late talkers overall ($M = 1.23$, $SE = 1.5$ for late talkers; $M = 4.9$, $SE = 0.92$ for typically developing children) and a significant 2-way interaction of word type and child type, $F(1,18) = 10.02$, $p = 0.005$. Two-tailed t-tests revealed that word type after the intervention made a significant difference for late-talkers, $t(5) = 2.77$, $p = 0.039$, such that late talkers in the high-probability condition increased in percentile significantly more than late talkers in the low-probability condition (high-probability: $M = 4.52$, $SE = 1.95$; low-probability: $M = -1.24$, $SE = 1.1$). For typically developing children, we see a marginal effect in the opposite direction, $t(13) = -1.87$, $p =0.084$ such that typically developing children in the low-probability condition increased in percentile slightly more than typically developing children in the high-probability condition

(See Figure 5).

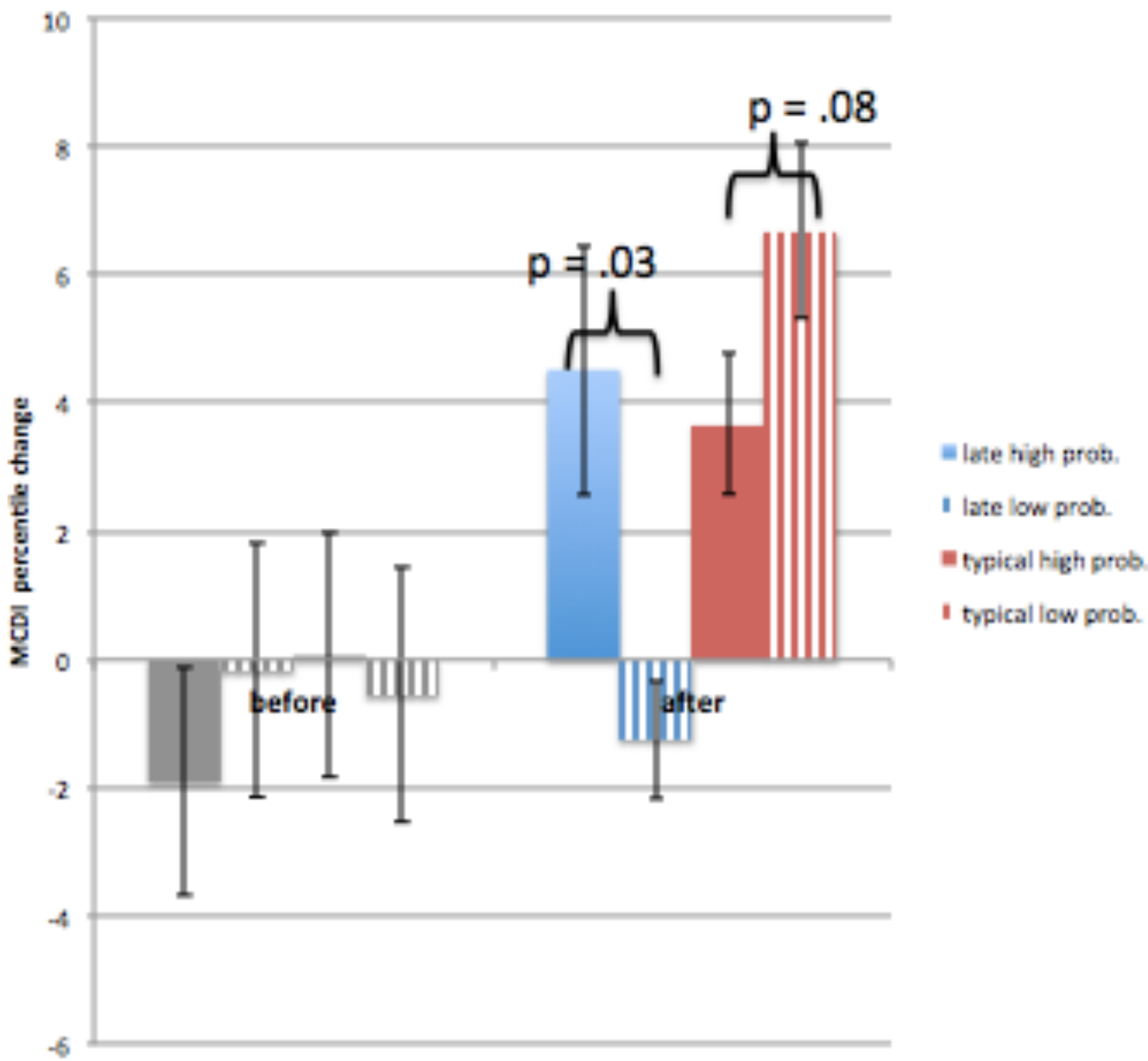

Figure 5: MCDI percentile change before and after intervention for late-talkers and typically developing children.

Discussion

The results of Experiment 2 show that the variable of word type does affect children's vocabulary growth when we look at different types of language learners as an additional variable. In addition, the effect of high-probability and low-probability intervention type on the child type is different before and after intervention.

When we look at before the intervention, from pre-visit1 to visit 1, there is no difference between the late-talker sample and typically developing sample in percentile change. There is also no difference between the high-probability and low-probability conditions before the intervention, indicating we have no biases favoring one type of language learner over another.

Things get interesting when we look at results after the intervention, from visit 1 to visit 2. There is no effect of word type; meaning one type of intervention is not better overall. There is a main effect of child type; overall late-talkers show less percentile difference than typically developing children. There is also a significant two-way interaction of word type and child type. This can be explained in a number of ways. One way is to consider high-probability selected words help everybody, while low-probability selected words only help typically developing children. A second way is to reason that late-talkers are helped more by high-probability selected words than low-probability selected words in vocabulary growth; however, typically developing children are helped by both.

The current literature indicates late-talkers have a different methodology in selecting words from their environment that they learn. This methodology indicates late-talkers limit their acquisition of semantically related words (Hills *et al*, 2010; Hills *et al*, 2009). Beckage, Smith, and Hills (2011) call this biased preference for novel words unrelated to the child's existing vocabulary the 'oddball' strategy. An example of a child exhibiting this 'oddball' strategy would be that a child is likely to learn the word “telephone” instead of “dog” after learning “cat” because telephone” has a weaker semantic relatedness to the word “cat” (Beckage *et al*, 2011). Results from Experiment 2 apply real data to the question of whether or not words are acquired differently for different word-learning populations; depending on what words they already know. Children benefit from learning words in an intervention when presented with words they otherwise wouldn't learn. If late-talkers have a tendency to learn “oddball” words and we teach them high-probability semantic-based words, our findings indicate this increases their vocabulary. In fact, the opposite may also be true for typically developing children (though we found only a marginal effect). If typically developing children are accustomed to learning words that are highly semantic-based in conjunction with their existing vocabulary, teaching them low-probability semantic-based words also increases vocabulary growth.

General Discussion

The work presented here makes two main contributions. The first contribution of the current study is as a test of whether the Aguilar (unpublished) models capture some aspect of actual growth. The findings suggest that the model proposed in Aguilar (unpublished) does in fact have characteristics of actual growth given children’s existing vocabularies because typically developing children tend to learn more high-probability words than low-probability words. This is not a case in which we can test the model’s predictions against reality directly because, by design, we are implementing an intervention. That is, we are teaching the children words that we think they are likely or unlikely to have learned on their own, and measuring the effect that this has on their language development trajectories. Within this framework, then, the results suggest that teaching children words that they otherwise would not have learned may bump them to a higher language trajectory. Interestingly, this may mean different things for late talkers and typically developing children. When driven by semantic-based features, the high-probability condition accurately represents words that have a high probability of being learned for typically developing children whom, according to Beckage *et al* (2011), tend to learn words that are semantically related to those in their existing vocabulary. This study adds to the work presented in Aguilar (unpublished) by using the preferential attachment algorithm proposed with real children's vocabularies. Future work includes thoroughly investigating how actual growth measures against predicted growth for real children's vocabularies and using features aside from semantics.

The second contribution is a measure of how well children under the age of two respond to individualized storybook interventions. The children in experiment 1 were around 18 months of age while the children in experiment 2 were around 20 months of age. Children in experiment 2 responded better to the task in both length and comprehension. Overall, this study exemplifies that children do in fact respond positively to an intervention with just sixteen words presented in a custom-made picture book at just 20 months of age. A picture book intervention goes beyond mere exposure; the saturation of training that occurs when children are read their custom-made book once a day for two weeks allows children to engage in repetition with the target words in the books. This repetition, particularly with the same picture and in the same order in the picture books may aid children in successfully completing the receptive vocabulary pointing task in which the target words presented are the same as those in their picture books. Future work on generalizing target words to other pictures as a receptive task may be a promising next step in these types of interventions.

This study also looks at the feasibility of making such a book intervention customized for individual children. The customization of each book was dependent on each child's existing vocabulary. Further analysis is merited as to the effects of customization for language acquisition interventions for children under the age of 2. However, findings from experiment 2 suggest that late-talkers and typically developing children may benefit from different types of interventions based on their existing vocabularies. What these findings suggest is children may benefit most in vocabulary growth by learning words that they were not necessarily going to learn soon in their original trajectory, given their typical environment. For late-talkers, this follows the "oddball" method proposed by Beckage *et al*, 2011. They suggest that late-talkers may tend to pick words to learn next out of those words that are semantically unrelated to the words they have recently learned. Teaching late-talkers semantically related words (in the high-probability condition for our study), exposes children to a subset of words they are unaccustomed to learning, and thus, increases their percentile gain. On the other hand, teaching typically developing children words – any words – seems to increase their percentile, although the results do suggest that, for them too, learning the words they would otherwise not have learned (low-probability words) might increase their overall percentile.

One thing to keep in mind is the question of how much about these words are children really learning? Parents report their child can identify the picture in the book as the target word, but the child has a hard time generalizing the target words to his/her environment. This has a number of explanations. Parents indicate certain words just aren't used at home. This includes words with close synonyms such as "sweater". A parent informed me that 'sweater' isn't used at home, but instead 'coat' and 'jacket' are used. Perhaps in future replications of this intervention, certain synonyms can be removed to avoid complications. Another explanation is certain nouns just don't exist in the child's environment. A parent reported that the child wasn't exposed to what a 'belt' was anywhere except for in his/her piggy book. On one hand, we want to teach children words they can easily generalize so they can truly gage the semantic characteristics of that word. On the other hand, exposing children to these words they don't typically encounter may be the driving force in increasing their vocabulary growth, as shown in the results from experiment 2. The biggest positive effect to introducing children to words they don't typically encounter, even if they are synonyms with words the child is currently exposed to, is parents have a tendency to start to point out these words that would normally go unnoticed in the child's environment. It has been shown that children play an active role in determining what is meaningful and relevant to them as their needs change and when parents respond contingently to their child's vocalizations and play activities they benefit more in expressive language than those children with less responsive parents (Tamis-LeMonda, Bornstein, & Baumwell, 2001). Parents play a significant role in their child's development. In fact, Sénéchal, Cornell, & Broda (1995) point out parents are very sensitive to their child's linguistic abilities, adapting their book reading behaviors accordingly. Future work includes a more thorough look at how parents interact with their children during the two-week period they have the book at home with them. In sum, the custom-made picture book intervention presented here plays an important role in informing others how well children under the age of 2 respond to storybook interventions.

Limitations and Future Work

It is important to highlight the limitations of the current study. The size of the sample is a big limitation in the study. The current study (both experiments included) had such a small sample of children. Further work looking at more late-talkers' vocabularies specifically, would provide a better picture of how an effective custom-made storybook intervention should be conducted. We aim to conduct such a study in the future to draw stronger conclusions. Also, a big limitation we face currently is that we are uncertain how sustainable findings will hold in the third visit. The third visits for all children should be finished in mid-May 2013. It is unclear how percentile growth will be affected by the intervention a month after the intervention took place. Do the sixteen words taught in the child's custom-made picture book really make a difference in the child's overall vocabulary growth trajectory? Finally, a limitation of the current study is we only have high-probability and low-probability semantic conditions. Aguilar (unpublished) was interested in the different roles of semantic features and phonological features separately in vocabulary acquisition. Future work includes using a high-probability and low-probability phonology condition in a similar way that semantics was used here.

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Appendix A

Piggy Book Example Pages

Where can piggy take a nap?

On a present?

No...that's silly.

Where can piggy take a nap?

On a piggy bed?

Yes! Piggy would love to take a nap on a nice, comfy piggy bed!